EXPRESS MAIL CERTIFICATE NO. EL163092479US
Attorney Docket No. T7029

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Assistant Commissioner for Patents
BOX PATENT APPLICATION
Washington, D.C. 20231

Sir:

Transmitted herewith for filing is the patent application of:

Inventor: **Elwood G. Norris**

Inventor: **James J. Croft III**

For: **PARAMETRIC LOUDSPEAKER WITH ELECTRO-ACOUSTICAL, ONE-STAGE DIAPHRAGM TRANSDUCER**

comprising 15 pages of specification, claims and abstract.

Enclosed also are:

X 3 Sheets of drawings (informal).

___ An Assignment of the invention to

___ A certified copy of an application.

___ An Associate Power of Attorney.

___ A Verified Statement to Establish Small Entity Status Under 37 C.F.R. § 1.9 and 37 C.F.R. § 1.27.

X A Certificate of Express Mailing by "Express Mail" certifying a filing date of **September 24, 1998,** by use of Express Mail Label No. **EL163092479US.**

X No fees are enclosed.

X No Declaration, Power of Attorney, and Petition are enclosed.

X Priority of application **Serial Nos. 08/684,311 filed on July 17, 1996, 09/006,134 filed on January 13, 1998, 09/006,689, filed on January 13, 1998, 09/006,133, filed on January 13, 1998, 09/004,090, filed on January 7, 1998 and 09/105,380, filed on June 26, 1998**, in the United States of America is claimed under 35 U.S.C. § 119.

___ Prior Art Statement, Form PTO 1449, and copies of cited prior art.

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PATENT APPLICATION
Docket No. **T7029**

CERTIFICATE OF MAILING BY "EXPRESS MAIL"

"Express Mail" Mailing Label No.: **EL163092479US**

Date of Deposit: **September 24, 1998**

I hereby certify that this patent application in the name of **ELWOOD G. NORRIS and JAMES J. CROFT III** for **PARAMETRIC LOUDSPEAKER WITH ELECTRO-ACOUSTICAL, ONE-STAGE DIAPHRAGHM TRANSDUCER**, together with two (2) sheet of drawings, and a transmittal letter, are being deposited with the United States Postal Service "Express Mail Post Office to Addressee", addressed to: BOX PATENT APPLICATION, Assistant Commissioner for Patents, Washington, D.C. 20231.

Dated this **24TH** day of **September, 1998.**

Respectfully submitted,

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Parametric Loudspeaker with Electro-acoustical , One-Stage Diaphragm Transducer

CIP of T3941, T6446, T6446CIP, T5287, T5388, T5462

BACKGROUND OF THE INVENTION AND RELATED ART

Field of the Invention

This invention relates to Parametric loudspeaker transducers. More particularly, this invention relates to Parametric Loudspeakers transducers that are based on film type diaphragms which involve a single stage, electro-mechanical conversion of ultrasonic voltage signals to ultrasonic compression waves.

Prior Art

A parametric loudspeaker is a sound emission system that directly emits high frequency sound waves in a medium such as air for developing audio output resulting from driving the medium into non-linearity. Such systems provide a highly directional loudspeaker that is effectively a virtual end fired array. Historically these devices have not been able to achieve high performance for multiple reasons, many of which relate to transducer performance.

Prior art efforts in parametric speaker applications have generally been limited to theoretical investigation of properties and applications. Commercial development of parametric products appear to have alluded the industry, based on lack of effective sound reproduction which is competitive with other conventional sound systems such as dynamic and electrostatic speaker systems. Even where parametric speaker offer a distinct advantage such as with enhanced directionality, commerical success has been nominal.

Parametric speakers rely on effective coupling of ultrasonic sound output of a unique nature of a unique nature with surrounding air. Both theoretical and commercial product research has focused primarily on the of emitter devices that use piezoelectric bimorph structures, also known as

piezoelectric benders. These devices use two layers of piezoelectric material that are bonded to each other and are driven out of phase. As one layer expands in length, the other contracts, providing output movement in a plane 90 degrees to the expansion/contraction direction. While the force of these devices is quite high the actual displacement and coupling to the air is rather poor. Therefore, successful performance of the bimorph relies on a second stage of conversion process in which the localized movements of the bimorph are amplified within the surrounding air. This is accomplished with various air matching means that consist of plate and disc structures that are comparable in size to a wavelength of the frequency of interest.

In order to develop meaningful sound pressure level (spl), many of these devices are spaced along a support plate or other support structure. See, for example, Tanaka et al, U.S. patent 4,823,908 and other parametric patent disclosure provided as part of an accompanying prior art statement which suggest the use of hundreds of bimorph devices, including clusters of 500 to over 1400 units. Because each of these devices represents a localized emitter, drive intensity immediately in front of each device can get very high at each small point in space causing the air to be driven into shock. Such premature nonlinear action has been discovered by the present inventors to have serious adverse effects upon the general process of parametric loudspeaker operation.

To a large extent, prior art efforts for enhancement of SPL has focused on the multiplication of bimorph emitters, requiring ever increasing power demands. While it has been perceived that this can provide high ultrasonic output, the present inventors have discovered a number of limitations to this approach in terms of phase matching errors due to variations from device to device, distortion and bandwidth problems and the associated cost and complexity of using so many separate devices. Indeed, the phase relationships of these separate devices are such that the total output of many devices used as a cluster does not add up to the amount predicted by just summing all the devices. This phase loss and lack of matching affects both output and directivity which can have many side

lobes due to phase errors. In addition, it appears that these devices are also characterized by the fact that they tend to have many harmonic resonances and anti-resonances which are reflected in the demodulated audio of the parametric loudspeaker.

An example of the prior art is described in the article *The audio spotlight: An application of nonlinear interaction of sound waves to a new type of loudspeaker design* by Yoneyama and Fujimoto. Their use of an array of 547 piezo bimorph type transducers typifies previous and subsequent prior art parametric loudspeakers. At a cost of approximately a dollar each, even in high quantities, the cost of a system can be over $500 to $1500 to achieve reasonable audio output.

Another factor which has perhaps channeled investigators to rely on bimorph devices is a perception that the emitter should be structured with dimensions corresponding to wavelengths of the ultrasonic energy to be emitted. This is in accordance with other types of ultrasonic devices, such as electrostatic emitters, which are constructed at a size corresponding to the wavelength of the lowest frequency of interest. Even when using these devices it is still required to use large device counts to achieve the required output.

Nevertheless, the present inventors are unaware of any successful efforts within the prior art where emitters other than bimorph transducers have been applied in parametric speaker design. This may be a result, in part, of parallel experience between dynamic speakers versus electrostatic speakers within the audio industry generally. For example, approximately ninety-five percent of audio systems sold in the world fall within the class of dynamic speakers, represented by a magnetic driving unit which is mechanically coupled to a cone or other form of acoustical driver. This type of system comprises a two stage speaker system wherein the first step involves an electro-mechanical process of converting the voltage signal of the audio output to a mechanical movement. This is followed by a second stage wherein the mechanical movement is converted to an acoustical conversion, such as with movement of the cone for displacement of compression waves.

Such dynamic speakers are able to generate high levels of volume, particularly at low frequencies because of the strength of the drive system. They are also well suited for adaptation within small spaces, enabling use with speaker housings limited to small rooms, automobiles, etc. The versatility of dynamic speakers and their simplicity of operation as represented by the moving cone have favored a substantially uninterrupted lead position over any other type of audio reproduction system. Furthermore, such development has include expensive and complex audio control problems such as were enumerated in parent application 08/684,311 , incorporated herein by reference. Accordingly, complex equalizing and cross-over circuitry has been developed, as well as damping techniques to handle heavy weights of magnetic components of the dynamic speaker.

In contrast, the electrostatic speaker industry has offered significant potential for commercial benefit; however, because of size requirements and construction limitations, electrostatic speakers have failed to capture a significant market share--less than 5%. Therefore, despite certain advantages offered by electrostatic speakers over dynamic speaker within the audio industry, commercial and research focus continues to predominate on the dynamic form.

It appears likely that this trend within the acoustic world has directly affected the direction research within the parametric field of sound reproduction. Specifically, virtually all development to date has been with the use of bimorph transducers, similar in construction to the dynamic speaker with its two stage operation. As noted above, bimorph systems have not realized the necessary results for commercialization of parametric speaker systems. Having failed to realize required levels of volume and quality with the "dynamic" form (bimorph transducer) of a ultrasonic emitter, there has been an apparent assumption by those skilled in the art that the lesser capable electrostatic or film-type emitter used for ultrasonic applications generally would be even less likely to perform in the parametric sound field. Therefore, those skilled in the art have not considered the use of broad film diaphragms or single-stage electro-acoustical conversion systems as being likely to succeed

with parametric sound.

Surprisingly, the present inventors have discovered that a single-stage conversion process using such transducers as electrostatic films, etc., offer significant advantages which are unique to the parametric speaker industry.

OBJECTS OR SUMMARY OF THE INVENTION

It is therefore an object of this invention to apply single-stage electro-acoustic technology to the parametric field of sound reproduction.

It is a further object of this invention to provide a high frequency emitter for use as a parametric loudspeaker that consists of a large area film transducer for which the largest dimension is many wavelengths in size relative to the carrier frequency of operation.

It is the further object that the invention is more than 10 wavelengths in dimension.

It is the still further object of the invention to have a substantially continuous diaphragm that therefore drives each portion of the air less for a given total amount of system output.

It is still further object of the invention to have a transducer that can deliver high output while minimizing distortion, phase shift, and harmonic resonances.

It is a still further object of the invention to have a transducer that minimizes side lobes in the directivity pattern of the primary frequencies.

It is a still further object of the invention to have a transducer that may be configured to provide control of the directivity pattern of the primary frequencies so that the beam width can be expanded to the diameter of the transducer system or even greater.

These and other objects are realized in a method for generating parametric audio output based on interaction of multiple ultrasonic frequencies within air as a nonlinear medium, said method comprising the steps of:

a) generating an electronic signal comprising at least two ultrasonic signals having a difference in value which falls within an audio frequency range;

b) transferring the electronic signal to an electro acoustical transducer diaphragm which couples directly with the air as part of a single stage energy conversion process;

c) converting the electronic signal at the diaphragm directly to mechanical displacement as a driver member of a parametric speaker;

d) mechanically emitting the at least two ultrasonic signals from the diaphragm into the air as ultrasonic compression waves; and

e) interacting the ultrasonic compression waves within the air to generate the parametric audio output.

Other objects and features of the present invention will be apparent to those skilled in the art based upon the following detailed description of preferred embodiments, taken in combination with the following drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1a is a drawing representing prior art parametric loudspeakers using multiple piezo bimorph transducers .

Fig. 1b is drawing representing another embodiment of parametric loudspeakers using multiple piezo bimorph transducers.

Fig. 1c is a drawing of bimorph transducers driving the air at small points in space and causing shock.

Fig. 1d is a drawing of a film transducer of the invention driving the air in a homogenous fashion that distributes the drive and reduces shock.

Fig. 1e is a drawing of a primary frequency waveform below shock level and at shock level.

Fig. 2 is a representation of a circular V grooved back plate for a large scale electrostatic film transducer.

Fig. 2a is a sectional view of a electrostatic back plate and diaphragm film.

Fig. 2b is a drawing of an electrostatic transducer with a curved back plate and diaphragm

Fig. 3 is a drawing of a rectified sine form of piezo film.

Fig. 3a is a drawing of a rectified sine form of piezo film with a quarter wave spaced back plate

Fig. 3b is a drawing of a shallow rectified sine form of piezo film.

Fig. 3c is a drawing of a shallow rectified sine form of piezo film with back plate.

Fig. 4 is a drawing of a sinusoidal shaped piezo film Fig. 4a is a drawing of a sinusoidal shaped piezo film with a backplate

Fig. 4b is a drawing of a sinusoidal shaped piezo film with a backplate and a curvature to open up the directivity angle of the primary frequencies.

Fig. 4c is a drawing of a sinusoidal shaped piezo film used in dipolar primary frequency/bipolar secondary frequency mode.

Fig. 5 is a drawing of piezo film with a back plate used in a dimpled form either concave or convex.

Fig. 5a is a drawing of piezo film used in a dimpled form convex.

Fig. 5b is a drawing of piezo film used in a dimpled form concave.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS AND DRAWINGS

Fig. 1 is a drawing representing a prior art parametric loudspeaker 10 using multiple piezo

bimorph transducers 11. These have been used with clusters of 500 to over 1500 bimorph transducers. One of the difficulties with parametric loudspeakers is that when driving the air at ultrasonic levels that provide reasonable conversion efficiency and loudness at the secondary resultant frequencies the air can be driven into a shock limit where the fundamental frequency cannot get any louder and only distortion components are increasing in level. This shock limit is worse when driving individual, small points of air space. The more confined the intensity the easier shock comes into existance.

Fig. 1c is a drawing of a group of bimorph transducers each driving the air at small points in space 12 and causing shock. Fig. 1d is a drawing of a film transducer 13 of the invention driving the air in a homogenous fashion that distributes the drive 14 and reduces shock. Fig. 1e is a drawing of a primary frequency waveform below shock level 15 and at shock level 16. One preferred embodiment of large scale film transducer is based on electrostatic drive principles. The electrostatic type transducer is uses a conductive backplate with a conductive film in close proximity to the backplate. A bias is applied to either the film or the backplate and both the film and the backplate are driven by two polarities of the drive signal. Fig.2 is a representation of a large scale electrostatic film transducer with a 21 circular V-grooved back plate. The back plate design may alternatively be pitted (concave) or dimpled (convex) in shape. Fig. 2a is a sectional view of a electrostatic back plate 23 and diaphragm film 22. When projecting high frequencies from large diaphragms compared to the wavelength of the frequency of interest the beam of sound can achieve such high directivity that the high frequencies will focus down to a tight beam.

This can cause to high of directivity and also cause premature shock formation of the sound waves due to overly high intensities being focused in a small airspace. By curving the diaphragm the radiation pattern can be opened up to have a directivity window comparable in width to the size of the transducer or even a somewhat wider spreading of sound to minimize shock limited

waveforms.

Fig. 2b shows an electrostatic film transducer with a curved backplate 23 and complimentary shaped film diaphragm 22 that solves this problem. Another embodiment of the invention utilizes piezo electric film (PVDF).This film expands and contracts when electrically excited and must therefore be formed to achieve acoustic output. A preferred forming of the piezo film 30 into a rectified sine shape is shown in figure 3. Fig. 3a is a drawing ofa rectified sine form of piezo film 30 with a quarter wave spaced back plate31. By spacing the backplate at a quarter wave from the film the output oof the emitter can increase up to 3 dB at the frequency whose wavelength is four times the distance from film to back plate. Fig. 3b is a drawing of a shallow rectified sine form of piezo film 32. Fig. 3c is a drawing of a shallow rectified sine form of piezo film 32 with back plate 31. Fig. 4 is a drawing of a sinusoidal shaped piezo film. This form is efficient in utilizing all of the film but for tall sine shapes the troughs can be out of phase with the peaks. This is overcome by having the peak to trough distances equivalent to approximately one half wavelength 34. Fig. 4a is a drawing of a sinusoidal shaped piezo film 33 with spaced backplate 31.Fig. 4b is a drawing of a sinusoidal shaped piezo film with a backplate and a curvature to open up the directivity angle of the primary frequencies tominimize shock formation and to open up the window of dispersion as in the above mentioned electrostatic example.

Most ultrasonic emitters and parametric loudspeakers are essentially monopol in radiation pattern. A parametric loudspeaker can be realized with the invention by using a open film without backplate such as PVDF, figure 4c, and radiate in a dipolar out-of-phase radiation pattern in the primary frequency range while simultaneously operating in a bipolar in-phase manner for all secondary parametrically derived signals. This could be used where one wanted to project highly directive, in phase sounds in two opposite directions. This is not practical to do with any prior art devices. Fig. 4C is a drawing of a sinusoidal shaped piezo film used in dipolar primary

frequency/bipolar secondary frequency mode. Another diaphragm form for piezo film is either a concave or convex dimpled structure. This shape may be achieved by thermo-forming the film or utilize foam support structure to push the film into this shape. Fig. 5 is a drawing of piezo film 51 with a back plate 52 used in ad impled form either concave or convex. Fig. 5a is a drawing of piezo film 51used in a dimpled form convex. Fig. 5b is a drawing of piezo film 51 used ina dimpled form concave.

CLAIMS

We claim:

1. A method for generating parametric audio output based on interaction of multiple ultrasonic frequencies within air as a nonlinear medium, said method comprising the steps of:

a) generating an electronic signal comprising at least two ultrasonic signals having a difference in value which falls within an audio frequency range;

b) transferring the electronic signal to an electro acoustical transducer diaphragm which couples directly with the air as part of a single stage energy conversion process;

c) converting the electronic signal at the diaphragm directly to mechanical displacement as a driver member of a parametric speaker;

d) mechanically emitting the at least two ultrasonic signals from the diaphragm into the air as ultrasonic compression waves; and

e) interacting the ultrasonic compression waves within the air to generate the parametric audio output.

2. A method as defined in claim 1, wherein step b) comprises the more specific step of transferring the electronic signal to an electrostatic transducer.

3. A method as defined in claim 1, wherein step b) comprises the more specific step of transferring the electronic signal to an electret transducer.

4. A method as defined in claim 1, wherein step b) comprises the more specific step of transferring the electronic signal to a piezo film diaphragm as the electro acoustical transducer diaphragm.

5. A method as defined in claim 1, wherein step b) comprises the more specific step of transferring

the electronic signal to a electro thermal mechanical film diaphragm as the electro acoustical transducer diaphragm.

6. A method as defined in claim 1, wherein step b) comprises the more specific step of transferring the electronic signal to a planar magnetic film diaphragm as the electro acoustical transducer diaphragm.

7. A method as defined in claim 2, wherein step b) comprises the more specific step of transferring the electronic signal to an electrostatic backplate having a surface configuration comprising circular v grooves operable as a stator member with respect to the diaphragm.

8. A method as defined in claim 4, wherein step b) comprises the more specific step of transferring the electronic signal to a piezo film diaphragm having a configuration of a rectified sine form.

9. A method as defined in claim 8, wherein step b) comprises the more specific step of transferring the electronic signal to a piezo film diaphragm which is supported by a backplate having a configuration of a rectified sine form.

10. A method as defined in claim 4, wherein step b) comprises the more specific step of transferring the electronic signal to a piezo film diaphragm having a configuration of a sinusoidal form.

11. A method as defined in claim 10, wherein step b) comprises the more specific step of transferring the electronic signal to a piezo film diaphragm which is supported by a backplate having a configuration of a sinusoidal form.

12. A method as defined in claim 1, further comprising the step of selecting a transducer diaphragm having a dimension greater than the wavelength of the ultrasonic frequencies at their lowest value.

13. A method as defined in claim 1, further comprising the step of selecting a transducer diaphragm having a dimension greater than ten times the wavelength of the ultrasonic frequencies at their lowest value.

14. A method as defined in claim 4, further comprising the step of selecting a transducer diaphragm having a convex curvature which generates a diffuse radiation pattern for emission of the parametric output.

15. A method as defined in claim 4, further comprising the step of selecting a transducer diaphragm having a concave curvature which generates a focused radiation pattern for emission of the parametric output.

16. A method as defined in claim 4, further comprising the step of selecting a transducer diaphragm having a dipolar propagation mode for which generates a diffuse radiation pattern for emission of the parametric output.

17. A method as defined in claim 4, further comprising the step of spacing the transducer diaphragm a quarter wave distance from a supporting backplate.

18. A method as defined in claim 1, further comprising the step of selecting a transducer diaphragm having a one-half wave length distance between between peak to trough of a sinusoidal form for the diaphragm.

19. A method as defined in claim 4, further comprising the step of providing a dimpled transducer

diaphragm comprising a monolithic sheet of film having closely spaced concave dimples in closely spaced, side by side array which generates a substantially uniform and homogenous radiation pattern for emission of the parametric output across the surface of the diaphragm.

20. A speaker device for generating parametric audio output based on interaction of multiple ultrasonic frequencies within air as a nonlinear medium, said device comprising:

a) a parametric signal generation system including an ultrasonic signal source, an audio signal source, and a modulating device coupled to the ultrasonic and audio signal sources for mixing the ultrasonic and audio signals for generating a resultant electronic signal comprising at least two ultrasonic signals having a difference in value which falls within an audio frequency range;

b) an eelectro acoustical transducer diaphragm coupled to the parametric signal generation system which also couples directly with the air as part of a single stage energy conversion process; and

c) support structure for positioning and stabilizing the diaphragm to enable mechanical displacement of the diaphragm as a driver member of a parametric speaker.

21. A device as defined in claim 20, wherein the transducer comprises an electrostatic transducer.

22. A method as defined in claim 20, wherein the transducer comprises an electret transducer.

23. A method as defined in claim 20, wherein the transducer comprises a piezo film diaphragm as the electro acoustical transducer diaphragm.

24. A method as defined in claim 20, wherein the transducer comprises an electro thermal mechanical film diaphragm as the electro acoustical transducer diaphragm.

25. A method as defined in claim 20, wherein the transducer comprises a magnetic film diaphragm as the electro acoustical transducer diaphragm.

ABSTRACT

A parametric loudspeaker that directly generates multiple high frequencies to indirectly create lower frequencies through the use of substantially monolithic, large area, film transducers that are generally larger than a wavelength of the carrier frequency in diameter or cross section. These large area film transducers include but are not limited to electrostatic, electret, piezo film such as PVDF, electrothermal mechanical film, and planar magnetic

APPENDIX OF DOCKET NUMBERS FROM PAGE 1 REFERRING TO PRIORITY APPLICATIONS

Attorney Docket No. T7029
Attorney: Vaughn W. North

T3941
Serial No. 08/684,311
Filed: July 17, 1996

T5287
Serial No. 09/006,134
Filed: January 13, 1998

T5388
Serial No. 09/006,689
Filed: January 13, 1998

T5462
Serial No. 09/006,133
Filed: January 13, 1998

T6446
Serial No.09/004,090
Filed: January 7, 1998

T6446.CIP
Serial No. 09/105,380
Filed: June 26, 1998

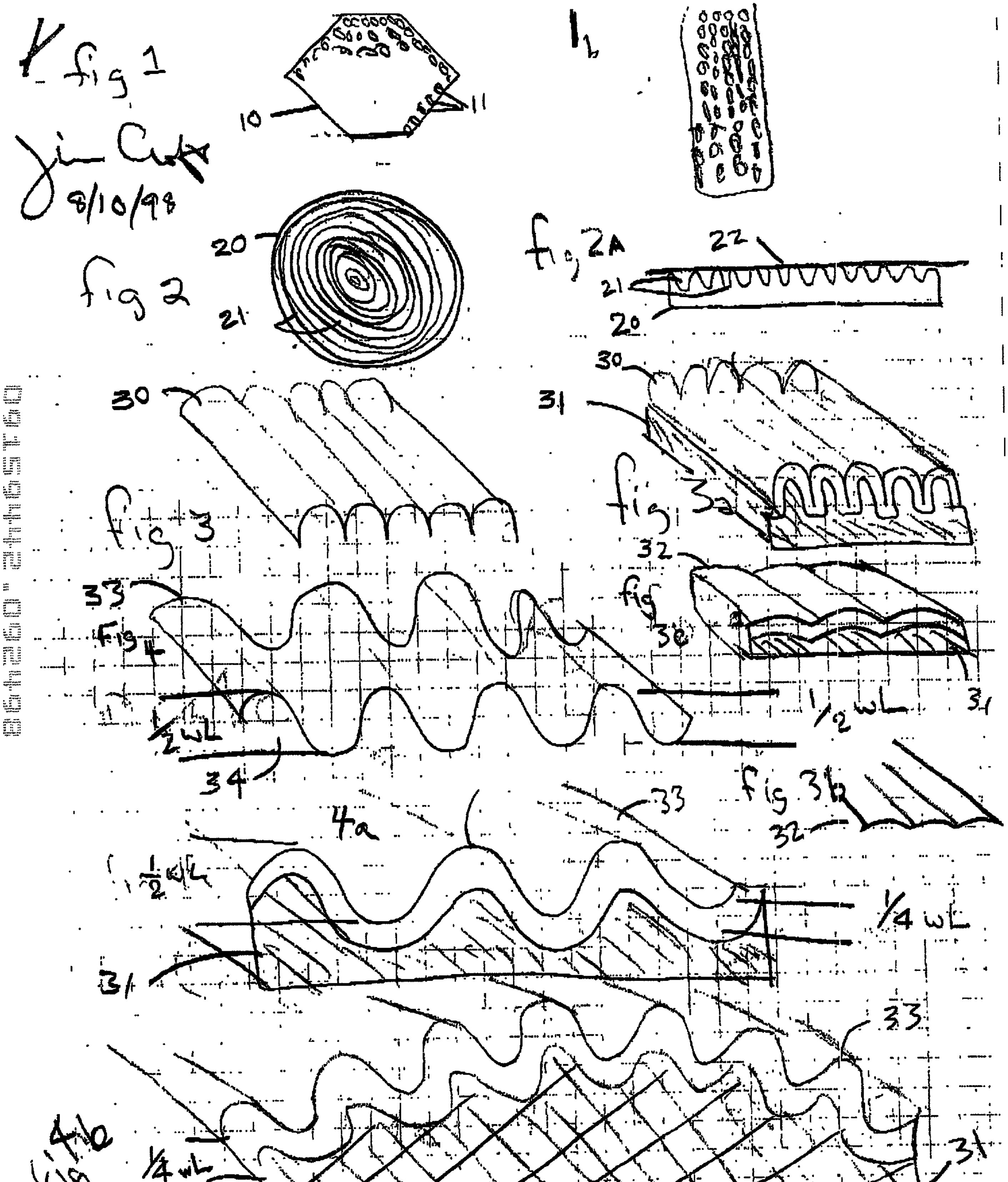
fig 1
Jim Croft
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11
1b
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fig 2
fig 2A
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30
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fig 3
fig 3a
32
33
Fig 4
fig 3c
1/2 wL
31
1/2 wL
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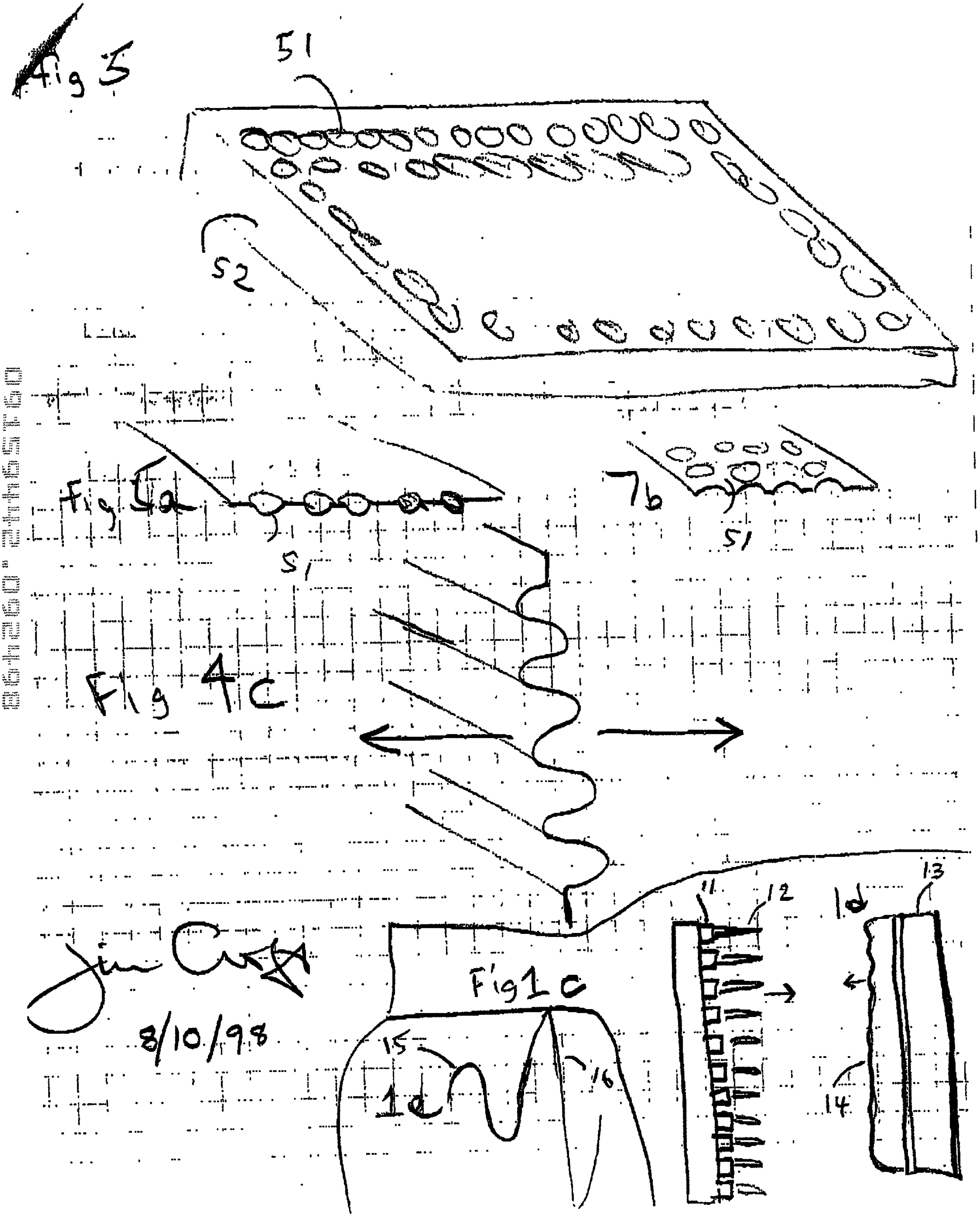
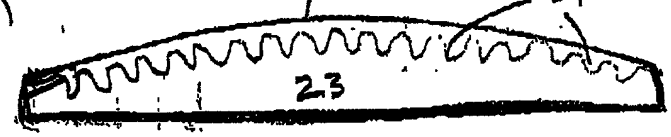


8/10/98

Fig 2b



curved Esl backplate

Piezo
bi-morph or bender

Non parametric claims